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Meteorological Message and Test Analysis Software for an Army Meteorological System

by James Cogan and Terry Jameson

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Army Research Laboratory
White Sands Missile Range, NM 88002-5501

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14. ABSTRACT
This report describes software packages that have been developed by the Battlefield Environment Division of the Computational and Information Sciences Directorate of the U.S. Army Research Laboratory (ARL) to generate meteorological (Met) messages from modeled and measured atmospheric soundings, as well as to provide a means of statistically analyzing the accuracy of the messages and ultimately the soundings from which they were derived. This report also provides some sample results using real data. The message generation algorithms have become part of the overall software package for the Meteorological Measuring Set – Profiler (MMS-P), which is currently in System Development and Demonstration and approved for initial limited production. The Test and Evaluation (T&E) Integration Process Team (IPT) for the MMS-P selected a later version of this software (also developed by ARL) in order to generate ground-truth messages during the Developmental Test (DT). The statistical analysis programs have generated information used by the T&E IPT and has assisted in the analysis of preliminary data for the Product Manager for Target Identification and Meteorological Systems. Expanded versions of these programs will provide statistical analyses for support of the DT and the consequent report on system accuracy. Both the message generation and statistical analyses software packages may be used for experiments that require any vertical structure of layered data, including new messages types that may be devised for non-line of sight systems of the future.

15. SUBJECT TERMS
Meteorological messages, test analysis software, developmental test, Meteorological Measuring Set - Profiler

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Summary

In coordination with the Product Manager – Target Identification and Meteorological Systems (PM-TIMS), we have developed a set of software programs that can compute several types of meteorological (MET) messages from atmospheric profiles produced by the Mesoscale Model Version 5 (MM5) on the Meteorological Measuring Set – Profiler (MMS-P) and from “ground truth” radiosondes. A variant of part of this software package has been incorporated into the MMS-P software and was used as the “standard” message software for the Developmental Test (DT) of the MMS-P, which was conducted at White Sands Missile Range (WSMR), NM, from January to April 2004.

In order to compare the MMS-P model’s output with ground-truth soundings, we developed a series of statistical analysis programs using the Matrix Laboratory (MATLAB) commercial software tool. The PM-TIMS adopted this statistical analysis software as a means to evaluate the accuracy of the MMS-P in several early tests of the system software and to analyze the data gathered at the DT. This software generates standard statistical measures of data quality that are specifically tailored to meet the needs of the MMS-P program. Furthermore, the programs can also be used to produce a variety of artillery accuracy comparisons, some of which have been published in earlier reports (Jameson and D’Arcy, 2004; Jameson, 2003; Jameson et al., 2002).

This technical report provides a short description of the programs in the Met message software package, followed by some real-world examples of input and output messages. The report also contains brief descriptions of the statistical analysis package, along with some examples showing comparisons between real Met data from the MMS-P and ground-truth radiosondes, as well as other accuracy evaluations.

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1. Introduction

Field artillery obtains meteorological (Met) data in the form of Met messages in several formats. While some apply to ballistic solutions for cannon or rockets, others provide detailed vertical structure for the target area. The latter types are likely to have application in future systems. In addition, vertical structure of the atmosphere is an important consideration for experiments of many types. The Battlefield Environment Division (BED) of the Computational and Information Sciences Directorate (CISD) of the U.S. Army Research Laboratory (ARL) has developed software packages for the following tasks: 1) one that can generate Met messages from model sounding output or measured atmospheric profiles from any sounding system, and 2) another that can analyze the statistical accuracy of those messages relative to those derived from "standard" or traditional sources of sounding data, and/or that can provide comparisons between messages from any two systems. In the latter case, one or both messages may be derived from model output.

Algorithms from the message generation package have become part of the overall software package for the Meteorological Measuring Set – Profiler (MMS-P) currently in System Development and Demonstration (SDD) and approved for initial limited production. The Test and Evaluation (T&E) Integration Process Team (IPT) for the MMS-P selected a later version of the message generation software (also developed by ARL) in order to generate ground-truth messages during the Developmental Test (DT). The Met Team at White Sands Missile Range (WSMR), NM, also requested this latter software to help in support of the DT and other tests. The message generation software discussed in this report is based on earlier work found in Cogan and Izaguirre (1993) and Cogan (1990). The current package provides a major upgrade and extension of those earlier message generation programs.

The statistical analysis programs have been used to generate information for the T&E IPT and have assisted the analysis of preliminary data for the Product Manager for Target Identification and Meteorological Systems (PM-TIMS). More recently these programs have provided critical support for the statistical analyses of the DT and the consequent report on system accuracy. This software is an outgrowth of a program used for earlier analyses, as described in Jameson and D'Arcy (2004), Jameson (2003), Jameson, et al. (2002), and earlier publications.

In this report we describe these software packages in some detail. The message generation software was written in the C programming language and the statistical software was written using the Matrix Laboratory (MATLAB) commercial development software environment. We also look at results from real data for several message types and provide statistical analysis of those results.

2. Message Generation Programs

The message generation programs produce several Met messages from vertical profiles of Met variables. They are coded in the C programming language, as per the standard set by the American National Standards Institute (ANSI). The current versions of the software can receive input soundings from a Meteorological Measuring Set (MMS), Marwin[1], and other radiosonde systems, as well as "53 level"[2] output soundings from the Mesoscale Model Version 5 (MM5) on the MMS-P. The first part of the program set consists of a group of format conversion programs, one program for each input sounding type that reads a sounding and puts the relevant data into a standard data structure. The second part of the program set converts the sounding data from the data structure into the several types of messages. While currently the messages are not output in the Teletype format—as found in the Department of the Army Field Manual 6-15 (1997) and other manuals such as the NATO Standardization Agreement 4082 (1984)—they do produce the same information in the same units. For example, the programs output virtual temperature in degrees K × 10 (e.g., 280.5 K represented as 2805) and wind direction in mils (to a good approximation, 1 degree = 17.7778 mils).

2.1 Software Components

The following paragraphs describe the program set and how the separate modules relate to each other. The required modules consist of C source files, include files, and two parameter files. The parameter files (*input_parameters* and *locdata*) are described in section 2.2.

There are two programs in the latest version. The first program (one of the *raobinput* programs) reads the rawinsonde observation (raob) data and stores the data in a standard data structure that is then used by the second program (*convertdata2*). Since each sounding system, even from the same manufacturer, has its own format (or set of formats), each type of raob has its own function for reading data from the sounding (hence the separate executable files). However, those functions provide a common data structure. There are two versions of the *convertdata* programs—one that uses the method (linear interpolation) of the MMS software package (personal communication) to compute the layer values of pressure, and another that uses the hypsometric formula (logarithmic function).

The source file names for the main functions of the *raobinput* set of programs include *raobinput2.c* for wind computation using data from a Global Positioning System (GPS), *raobinput_mmsb.c* for wind computation using data from a Radio Direction Finder (RDF), and

[1] Marwin is a registered trademark of the Viasala OY Corporation.

[2] The so-called "53 level" format is an upper-air format that was conceived and adopted early on in the MMS-P software development. It includes height levels that could define any zone in any of the artillery Met messages that could be created by the system.

others for wind computation using long range navigation (LORAN) and certain archived raob data. Functions called by the main function actually read the raob output. Again, different radiosonde systems of the same type (e.g., GPS) often produce output with different formats. Section 2.1.1 presents information on the different functions needed to handle the different formats.

Note that the first of these files (*raobinput2.c*) will run with or without header site information, as noted in the users guide. If the header contains no site data or incomplete site data, then the parameter file *locdata* must be available (see section 2.2).

Both programs use *flagsound.c* and *checkdata_c.c*. The function *readinputxxx.c* changes for each sounding format, where "xxx" delineates the type. For example, *readinputmmsb.c* is the function for MMS soundings from Ft. Sill, OK.

The executable file for the Marwin (2-sec) soundings is *raobinput2* (or *raobinput2g.exe*) for WSMR or *mmsbraobinput* (or *mmsbraobinput.exe*) for Ft. Sill, OK. Other executables handle output from other raob systems, such as *raobinputlor.exe* for LORAN sondes.

The *convertdata* programs work for all sounding types since they use the standard data structure. They also work for soundings from the MMS-P postprocessor (a version of the unified post-processor system (Stauffer, et al., 2002)) since the programs use a separate program to convert that output into the same data structure format. The source file names are as follows: *convertdata2.c*, *msgvalues2.c*, *flagsound.c*, *flagcomp.c*, *level.c*, *layer.c*, *spdrfromcomp_c.c*, *compfromspdr_c.c*, *clean_data_c.c*, *tvfromtemp_c.c*, *prscomp.c*, *readinputdata.c*, *writemetcms.c*, *writetams.c*, *writetacqs.c*, *writebwinds.c*, *writebaliss.c*, *checkdata_c.c*, *fixinput.c*, *bal_met.c*, and *msg_mod.c*. The include files are *convert.h* and *metstruct.h*. The executable file used after compiling is *convertdata2* (or *convertdata2.exe*). The version using the MMS method for pressure designates the main function as *msgvalues2_var.c*; the write functions take the extension "var," such as *writemetcms_var.c* (except for *writebwinds.c*, which remains the same since pressure is not part of its output). The executable file is *convertdata2v* (or *convertdata2v.exe*).

A short description of each source file follows. Brief headers in those files and in-line comments also help to describe the purpose of the files and the code within the files. Figures 1-3 provide "high level" block diagrams of the program.

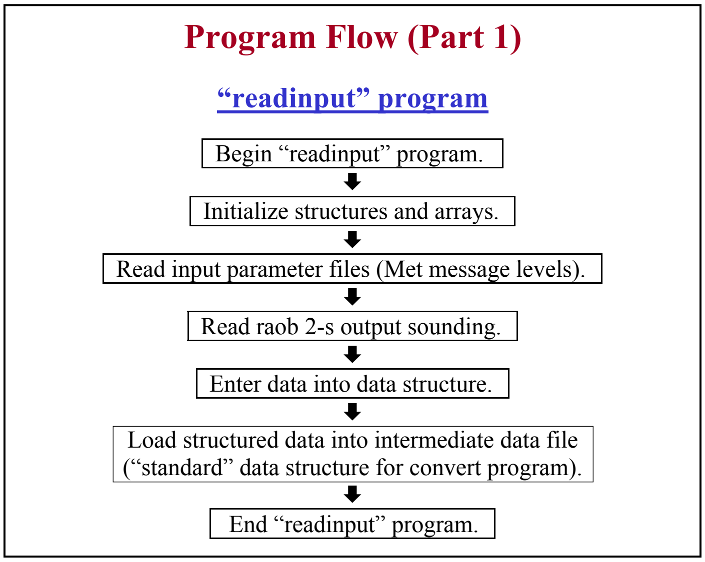

Figure 1. Block diagram of the first part of the program that loads 2-s raob output to a temporary file in the standard data structure used by the conversion routines.

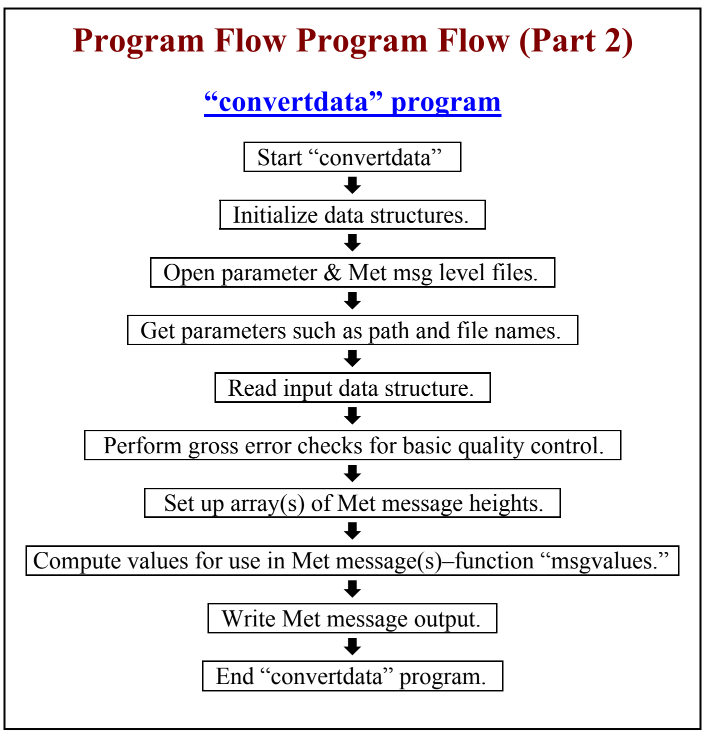

Figure 2. Block diagram of the conversion program. The main function calls the function *msgvalues*, which in turn converts the data in the standard structure into zone values for the several Met message types.

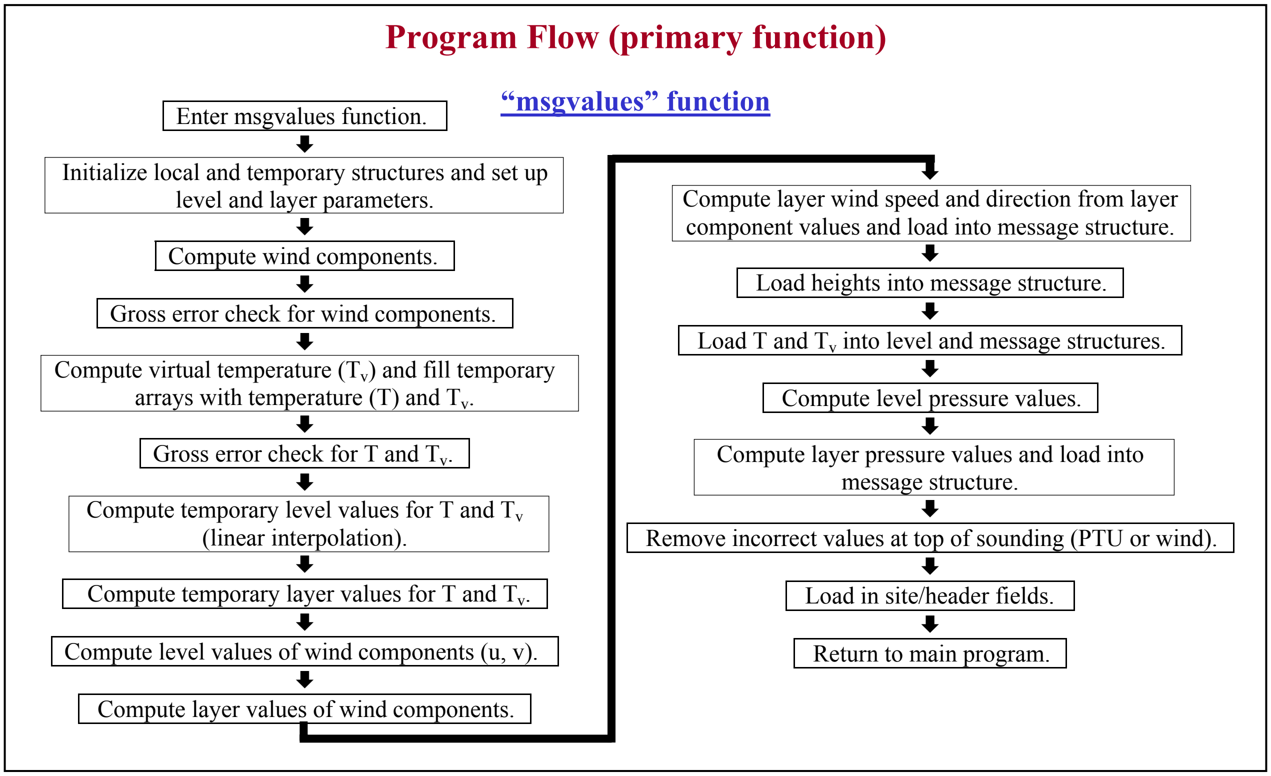

Figure 3. The primary function of the program called from the main function *convertdata*. This function does the level and layer calculations, changes *u* and *v* components into wind speed and direction, and inserts the output values into the appropriate data structure. PTU refers to pressure/temperature/humidity.

2.1.1 Reformat raob Data into Standard Data Structure

1. *raobinput2.c* (or *raobinput_mmsb.c*): This file contains the main function of the reformatting program. It calls the function for reading the data in the particular data format, and then stores those data in the standard structure. Use the first file for GPS and LORAN soundings and the second for MMS (RDF) data.

2. *readinputmms.c*: The function in this file (*readinput*) reads the ASCII file containing the MMS raob data. Other versions read data in other formats—e.g., *readinputokc.c* was used for data gathered at the Joint Urban 2003 experiment in Oklahoma City; *readinput2.c* was used for GPS 2-second data; and *readinputmmsb.c* was used for MMS (RDF) data. Additional versions read data from LORAN sondes, data from sondes used in the MMS-P, and data from archived raob soundings.

3. *checkdata_c.c* and *flagsound.c* are described in section 2.1.2.

2.1.2 Convert Sounding in Data Structure into Met Messages

1. *convertdata2.c*: The *convertdata2* program is the main program or function. (In an earlier version it is contained in the file *convertdata.c*.) This file converts sounding data in the standard structure into various Met message types (e.g., computer Met message (METCM)). The output from this program may not have the exact Met message format or formats, but it does give the correct values for Met message levels or layers.

2. *msgvalues2.c*: The *msgvalues2* function computes level and layer values for a Met message. (For the version using the MMS method of computing layer pressure, it is found in *msgvalues2_var.c*.) This function also removes parts of data lines with missing or "bad" data values. In the current version, if pressure, temperature, or humidity is missing, then all three values are removed from the data line, and they are not used in the level or layer calculations. The same holds for wind speed and direction; if one is missing, both are removed from the data line. The level values are the values at the message heights as found in the input height file for each message type. For example, the file *metcm_lvls* contains heights for the METCM message. The layer values are the weighted mean values, or integrated mean values, for layers as defined by the array of message heights in those files.

3. *level.c*: The *level* function is a general linear interpolation program for any defined atmospheric structure of heights and layers. It produces values at levels defined in the input array of heights. It requires observations for 2 to *n* heights, where *n* is no larger than the maximum array size (e.g., 3,000). The minimum output height cannot be less than the minimum observation height, the maximum no more than the maximum observation height.

4. *layer.c*: The *layer* function generates values for weighted, or integrated mean, layers defined by the levels in the input array. It produces values for any defined atmospheric structure of heights and layers. For example, the output could contain the layer values used in the METCM message (all values above the surface). Line 0 is the lowest line in the message and contains the surface values. It is the only line that is not a layer value in the several message types.

5., 6. *spdrfromcomp_c.c* and *compfromspdr_c.c*: The *spdrfromcomp* and *compfromspdr* functions convert wind components into wind speed and direction, and wind speed and direction into components, respectively. Either can generate or use speed and direction in regular units (ms^{-1} and degrees) or in artillery units (knots and tens of mils). In the *convertdata* program, regular units are used. The conversion to artillery units takes place later in the program. Note that some messages may not use artillery units.

7. *clean_data_c.c*: The *clean_data* function provides a gross error check on the data. The primary function *clean_data*, and the included function *sanity_check*, operate to see if the data values are within predefined bounds. A data value is set to the value for missing data (ERROR = -999.0 or IERROR = -999) if it lies outside of the "useful data" envelope.

8. *tvfromtemp_c.c*: The *tvfromtemp* function converts sensible temperature into virtual temperature.

9. *prscomp.c*: The *prscomp* function computes pressure from height and virtual temperature using the standard hypsometric equation.

10. *readinputdata.c*: The *readinputdata* function reads one input sounding in the data structure format for conversion into one or more Met messages. It can read in any number of Met data lines up to the upper limit as defined by the define constant MAXHEIGHT. However, for processing into a Met message at least two lines are needed, one of which has to be the surface.

11.-15. *writemetcms.c*, *writetams.c*, *writetarqs.c*, *writebwinds.c*, and *writebaliss.c*: The respective functions (e.g., *writemetcm*) format the output data into METCM (metcm), Target Area (tam), Target Acquisition (tacq), Basic Wind (bwind, formerly Fallout Wind), and Ballistic Met (balis) message type values (e.g., wind direction in tens of mils in the METCM), and writes the results into the files that have most, or all, of the name of the original input file (e.g., *07-1500*), plus a suffix with the name of the message type (e.g., *07-1500-MMS_metcm*).

16. *checkdata_c.c*: The short *checkdata* function prints certain data in the *struct_sound* format. It provides an easy-to-use means to check data values at different points within the program.

17., 18. *flagsound.c* and *flagcomp.c*: The *flagsound* and *flagcomp* functions initialize numerical fields in the "sound" and "windcomp" structures, respectively, using the ERROR or IERROR values as defined in the *convert.h* include file. These values are -999.0 and -999, respectively.

19. *fixinput.c*: The *fixinput* function provides a simple means to adjust the input in case of a bad or missing data value within a data line (as determined by the *clean_data* function). The line with the bad or missing value is simply removed. This option exists in the current version.

20. *msg_mod.c*: The *msg_mod* function replaces pressure/temperature/humidity (PTU) or wind computed layer values at the top of a message with the ERROR value (-999.0) where missing input data values appear in the sounding, from the top down, and are included in the layer computations. In the latest version, layer values are computed for all variables if the PTU or wind values are "good" at the top of a message. This function removes the "bad" PTU or wind values. For example, if the values of wind speed and direction are missing at the topmost altitudes, but there are good values of temperature, pressure, and humidity, the function will replace the computed bad layer wind values with -999's. Normally, this function would only replace values at the uppermost one or two layers.

2.1.2 Include Files

1. The file *convert.h* provides the function definitions, almost all of the define constants, and the standard C include files (e.g., *stdio.h*).
2. The file *metstruct.h* provides the structure definitions, plus some define constants.

2.2 Guide to Use of Message Programs

1. Check for the parameter file *input_parameters* in the same directory as the program (current configuration, but can be changed). The file in the present form has the directory or path of the input data file (see bullet point 4) followed by two numbers, the first is the minimum height used in the gross error check of the input sounding. Currently the first number (minimum height) is set to 0 m (float). A different value may be useful if the input heights are at mean sea level (MSL). The second number is an integer value used to determine which method for "fixing" an input sounding with one or more bad or missing data values; currently it has a value of 1. These parameters are called "minheight" and "fixswitch," respectively. If the file is not found, default values are used (0 m and 1, respectively). A 0 value for fixswitch means "halt the program if a bad data value is found." A value of 1 (default) means "either remove the data line with the bad value (some older versions)" or in the most recent version, "remove only groups of bad data fields," that is wind speed/direction or PTU. Later versions may treat one or more of the PTU variables separately. The next-to-last line of the parameter file is the output directory. The last line has a character that is used to determine whether or not to use the *locdata* parameter file (raob launch site data). This parameter file is required when the header does not contain the needed site information, as for some WSMR soundings.
2. Check for the input files *metcm_lvls*, *tam_lvls*, *tacq_lvls*, *bwind_lvls*, and *balis_lvls*. The program will halt if no files are found, but will continue if at least one is available. These files contain the heights for each type of message: METCM, tam, tacq, bwind, and balis. These heights are the surface (0 m) and the boundary values for the message levels (e.g., for the METCM: 200 for the 0-200 m layer, 500 for the 200-500 m layer, 1000 for the 500-1000 m layer, etc.). At least one of these files is required for the program to produce at least one message. These files are in the same directory as the program (current configuration, but can be changed).
3. Check for the parameter file *locdata* in the same directory as the program (current version) if the soundings are from certain raobs (e.g., some LORAN soundings). It is not used for raobs in the format of the MMS (RDF) soundings or most GPS soundings (2 or 10 second). This file contains raob launch site information, such as site name (e.g., JAL for Jalen), latitude, longitude, elevation, and the nature of the input data heights—i.e., whether they are MSL (normal for 10-s and 2-s data) or above ground level (AGL). This last item must match the type of data output from the rawinsonde system. If not, the program will produce incorrect message values for levels around and below the site elevation, or it simply may not function. The site elevation should be the same as the first (surface) raob height. If not, the program will account for the difference if the elevation is too low, or default to the raob value if the elevation is too high. If the difference is large, the message values may have significant errors.
4. Check for input sounding data, that is, a raob output sounding in the 2-s (also 10-s) format in the appropriate directory (it should be the same as listed in the *input_parameters* file). A sample raob filename for data from Ft. Sill, OK, is *03-0700*. Because of the wide variety of header size and amount and type of information, the file is edited manually in order to strip the header of duplicated and/or unneeded information. In addition, many MMS soundings have partial METCM messages embedded in the sounding, with lines of

sounding data before and after. A modified file is denoted with the suffix "m" or "m2" (for example, *03-0700m* or *WSD30271m2* for a MMS or WSMR sounding, respectively). A change in the format will abort the program or produce erroneous results. At least two data lines (one of which must be the surface) must be available for the program to run.

5. A short script may be used instead of the following paragraph, and is briefly described in bullet point 7. This paragraph will describe the programs whether they are run separately or as part of the script. Run the first program by typing, for example, `mmsbraobinput` for MMS raobs from Ft. Sill, OK, or `okcraobinput` for the MMS raobs from Oklahoma City (Joint Urban 2003 experiment), followed by the input file name. For instance, type the command line `mmsbraobinput 28-0700m`. With the input now in the sounding structure format (the file name is *inputdata*), type the command `convertdata2` (see the next paragraph). NOTE: Some systems, such as Cygnus, require a "./" before the executable file.

   The most recent version of *convertdata* (produces the same output) is called *convertdata2* and is used in the same manner as *convertdata*. Another version named *convertdata2v* uses the MMS formula to compute Met message pressure. It is used in the same way as the other versions (e.g., type `./convertdata2v`). The file *convertdata2v* was used in the set of software for the DT test.

6. The output data are found in the output directory (the next to last line of the *input_parameters* file). The output file has the input file name concatenated with the suffix *_metcm*, *_tam*, etc. If one of the input *lvls* files was not in the appropriate directory, the program will not generate the related output. For example, if *tam_lvls* is not found then the program skips the computation of *03-0700m_tam*. The output variables are those found in the Met messages, but at this time not in the exact format. For example, for METCM wind speed is in knots and wind direction in tens of mils.

   The program that uses the MMS formula for pressure generates output with the additional suffix of *_var*. For example, it produces a file *28-0700m_metcm_var* from MMS 10-sec output having the name *28-0700m*.

7. The script file name is either *raobmsg_MMS* (MMS RDF at Ft. Sill, OK) or *raobmsg_2g* (GPS 2-second sounding at WSMR) and is run by typing the name followed by the input file name (e.g., *raobmsg_MMS 28-1500m* for a MMS sounding at Ft. Sill, OK). Other scripts may be written for other input types (e.g., for LORAN raobs). Certain information otherwise printed on the screen is sent to a log file named *msglog_raob*. A new log file is created for each run in the current version.

2.3 Input and Output Samples

The ASCII soundings produced by rawinsonde systems have headings that vary in size and content, and in some cases, have extra heading lines or partial Met messages imbedded in the sounding data (some MMS). An example is given in the appendix. After manually editing to remove the extra lines, we have an input sounding, as seen in table 1. Table 1 shows the header information and the initial 30 seconds of "2-second data" (a data record is output once every 2 seconds) from a GPS radiosonde at WSMR. The full sounding ended after 95 minutes. In some

cases no location, latitude, longitude, or elevation information appears in the rawinsonde system header. In that case, a reduced header is used without those lines (not shown).

Table 1. A partial 2-second sounding from a WSMR GPS radiosonde.

Station: 72269 WSD
Location: 32.40 N 106.37 W 1216 m

Started at: 27 JAN 03 18:30 UTC

Time		AscRate	Hgt/MSL	Pressure	Temp	RH	Dewp	Dir	Speed
min	s	m/s	m	hPa	degC	degC	deg	m/s	
0	0	0.0	1216	887.1	14.1	23	-6.7	240	1.0
0	2	8.0	1232	885.3	12.0	25	-7.4	297	0.9
0	4	5.0	1236	884.8	11.9	25	-7.5	318	0.9
0	6	4.2	1241	884.4	11.8	25	-7.6	325	0.9
0	8	3.6	1245	884.0	11.7	26	-7.2	327	0.8
0	10	3.3	1249	883.5	11.6	26	-7.2	327	0.8
0	12	3.1	1253	883.1	11.6	26	-7.2	329	0.7
0	14	2.9	1257	882.7	11.6	26	-7.2	333	0.7
0	16	2.8	1261	882.2	11.6	26	-7.2	337	0.6
0	18	2.6	1263	882.0	11.6	26	-7.2	341	0.6
0	20	2.7	1269	881.4	11.4	27	-6.9	346	0.6
0	22	2.7	1275	880.7	11.3	27	-7.0	356	0.5
0	24	2.7	1281	880.1	11.2	27	-7.1	8	0.5
0	26	2.7	1287	879.5	11.1	27	-7.2	22	0.5
0	28	2.9	1296	878.6	11.0	28	-6.8	37	0.5
0	30	2.9	1304	877.7	10.9	28	-6.9	60	0.6

NOTE: UTC = universal time coordinated; AscRate = ascent rate of the sonde; Dir = wind direction; and Speed = wind speed.

The program produces five types of message data: METCM, tam, tacq, bwind, and balis. At the request of the PM-TIMS, the programs were revised to include extra output for the METCM (temperature) and tacq message (virtual temperature) for DT purposes. A variant of the program with a modified output function produces the METCM in a Teletype-style format similar to that of the MMS.

A complete set of sample output types may be found in the appendix. Table 2a contains data for the METCM message in the form requested by several of the users, and table 2b shows the same data in a format similar to that produced by the MMS. Note that in table 2a there is an extra column containing sensible temperature that is not part of the METCM; this column was added at the request of the PM-TIMS for use in the DT data analysis. Tables 2a and 2b show only the first 10 lines (The appendix presents a complete message).

Table 2a. A sample of output with data for a METCM message.

```
METCM output
Date: 28MAR04   Time: 16:02  Latitude:  32.37000     Longitude: -106.47000
Elevation: 1283.00     Ceiling:  -999.0     Visibility:  -999.0
 Line    Height  Wind Direction  Wind Speed   Virt Temp  Pressure  Temperature
           (m)   (tens of mils)     (kt)       (K*10)      (mb)       (K*10)
  0          0         18            12         2890        877        2887
  1        200        631            10         2860        867        2856
  2        500        592             9         2840        841        2836
  3       1000        573             9         2809        801        2805
  4       1500        559            14         2780        754        2778
  5       2000        511            13         2771        709        2769
  6       2500        515            14         2750        666        2749
  7       3000        535            16         2722        626        2722
  8       3500        510            19         2687        588        2687
  9       4000        494            23         2655        551        2655
 10       4500        480            25         2621        517        2621
```

Table 2b. A sample of output with data for a METCM message, but in the standard Teletype-style format.

```
METCM1 324065 281600 128877

00018012 28900877
01631010 28600867
02592009 28400841
03573009 28090801
04559014 27800754
05511013 27710709
06515014 27500666
07535016 27220626
08510019 26870588
09494023 26550551
10480025 26210517
```

3. Statistical Analysis Programs

Before the T&E IPT could approve the use of the *convertdata* programs in the DT, we needed to ascertain whether or not the code could correctly generate Met messages. The code was intended to be used to emulate a MMS, as is currently deployed by Field Artillery (FA) units, since the MMS was considered to be the standard against which the MMS-P would be compared. The WSMR Met Team was tasked to collect raw, 2-second data files, from which *convertdata* would generate the appropriate ground-truth Met messages[3]. The T&E IPT required that messages produced by *convertdata*, using the 2-second format as input, be compared against messages

[3] At the time of the DT planning, the Met Team did not have software installed in their Marwin units that could directly generate the appropriate Met messages.

coming directly out of a MMS. A high degree of correlation had to be proven before Met messages generated by *convertdata* could be accepted as ground truth.

During the Met accuracy phase of the SDD, sounding data files were collected by FA training units at Ft. Sill, OK. A number of these files were provided to ARL from the summer of 2001 Oklahoma collection period. Each data file contained both standard Met messages as well as 2-second format[4] messages, all from the same sounding. Thus, we were able to run *convertdata* to generate Met messages and compare them with the standard messages coming directly from the MMS.

A MATLAB program called *cmm_compare.m* was written to generate the statistical comparisons between Met messages produced by *convertdata* and those taken directly from the MMS. In *cmm_compare.m*, both types of Met messages are read into arrays, zone-by-zone. The Met parameters of interest were virtual temperature, pressure, wind speed, and wind direction. Four statistical analysis values—Mean Bias (MB), Mean Absolute Error (MAE), Root Mean Square Error (RMSE), and Correlation Coefficient (CC)—were then calculated for each of the Met parameters.

MB is simply the differences between the MMS message and the *convertdata*-generated values, averaged over all Met message zones into one value. This value can be a positive or negative number. For example, if at every zone the *convertdata* virtual temperature was 1.0 K warmer than the MMS, the MB would be +1.0 K. The MB indicates the general trend in the differences (errors). It was desirable to find a very small MB, indicating the greatest conformity between *convertdata* and the MMS; however, it was possible that at some of the zones the differences could be largely negative and at others largely positive, and yet the MB would still average out to a small value.

The MAE is the average of the absolute value of the differences and is not susceptible to the kind of error seen with the MB. Thus, the MAE is always a positive number. For example, if at some of the zones the virtual temperature differences (MMS value minus the *convertdata* value) were -1.0 K, and for the remainder of the zones, the differences were +1.0 K, the MAE would simply average out to 1.0 K. The MAE is an indicator of how well the differences are falling into "error bounds," without regard to the sign of the errors.

The RMSE is the "square root of the mean of the errors squared." Put another way, at each zone the difference between *convertdata* value and MMS value (the error) was squared, the mean (average) value of the squared errors was calculated, and then the square root of that mean value was determined. The RMSE is another indicator of how well the differences are falling into error bounds. In RMSE, outliers receive greater weight, so this value is generally larger than MAE and is therefore considered to be a slightly more conservative statistical parameter.

---

[4] The time resolution was actually in 10-second time increments; however, the format is identical to the 2-second version.

The CC is a dimensionless number that indicates how closely one set of data (the *convertdata*-generated values) is associated with another dataset (the MMS values). A CC of +1.0 indicates a perfect correlation between the two datasets (i.e. *convertdata* has perfectly calculating the zone values as judged against the MMS). A CC of 0.0 indicates that no correlation exists between the two datasets, which would mean the *convertdata* code was not correctly calculating the Met parameters values at all.

The *cmm_compare.m* code was originally written to compare METCM messages. There were 11 cases selected for analysis from the dataset from Ft. Sill, OK, that had full, 26-zone METCMs. For each case, *convertdata* was run on the portion of the data file containing the 10-s format and a METCM was produced. Next, the MMS METCM was extracted from the data file and both Met messages were input to *cmm_compare.m*. The results of the 11 case comparisons are listed in table 3.

Table 3. Computer Met message comparison statistics.

COMPARISONS BETWEEN MMS METCM AND 10-S METCM FT. SILL, OK												
	June 27	**June 28**	**June 29**	**July 03**	**July 05**	**Aug 08**	**Aug 09**	**Aug 10**	**Aug 13**	**Aug 14**	**Aug 15**	**AVG**
DIR MB	0.40	-1.30	-1.40	0.40	0.90	0.50	1.70	-2.70	-4.80	-5.30	3.20	**-0.76**
DIR MAE	2.90	3.90	5.00	5.70	7.00	5.20	1.70	6.40	7.40	8.80	5.90	**5.45**
DIR RMSE	6.10	7.50	11.90	8.10	13.20	7.90	5.10	12.40	19.70	22.60	14.00	**11.68**
DIR CC	1.00	1.00	1.00	1.00	0.99	1.00	1.00	1.00	1.00	0.99	1.00	**0.99**
SPD MB	0.00	-0.10	-0.20	-0.10	-0.10	0.00	0.00	0.00	0.00	0.10	0.00	**-0.04**
SPD MAE	0.10	0.40	0.30	0.30	0.30	0.00	0.00	0.00	0.00	0.20	0.10	**0.15**
SPD RMSE	0.30	0.50	0.50	0.40	0.50	0.20	0.20	0.00	0.00	0.40	0.40	**0.31**
SPD CC	1.00	1.00	1.00	0.99	1.00	1.00	1.00	1.00	1.00	0.99	1.00	**0.99**
TMP MB	0.00	-0.10	-0.10	-0.10	-0.10	0.00	0.00	0.00	-0.10	-0.10	-0.10	**-0.06**
TMP MAE	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	0.10	**0.10**
TMP RMSE	0.20	0.10	0.10	0.10	0.10	0.10	0.10	0.20	0.10	0.10	0.10	**0.12**
TMP CC	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	**0.99**
PRES MB	-0.10	-0.20	-0.10	-0.30	-0.20	-0.10	-0.10	0.00	-0.30	-0.20	0.00	**-0.15**
PRES MAE	0.10	0.30	0.20	0.30	0.30	0.10	0.10	0.10	0.30	0.20	0.00	**0.18**
PRES RMSE	0.40	0.40	0.30	0.40	0.40	0.40	0.30	0.40	0.50	0.50	0.20	**0.38**
PRES CC	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	**1.00**

NOTE: DIR indicates wind direction (measured in mils), SPD indicates wind speed (measured in knots), TMP indicates virtual temperature (measured in K), and PRES indicates air pressure (measured in hectopascals, or mbar)[5].

[5] Note that in the METCMs themselves, wind direction is listed in tens of mils and virtual temperature in tenths of degrees K. The appropriate conversions to the units of measure indicated above are made by *cmm_compare.m* before the statistical comparisons are calculated.

For example, in the June 27 comparison, the Mean Bias for wind direction was +0.40 mils. Averaged over all 11 cases, the MB was -0.76 mils. Because there was some fluctuation plus and minus, the average MB was quite small, whereas the MAE and RMSE values for direction were significantly larger (5.45 and 11.68 mils, respectively). (However, to put it in perspective, the 11.68 mils equates to about 0.65 compass degrees). The CC in direction between the two Met messages was an almost perfect 0.99.

The other three Met parameters showed extremely low RMSE values and nearly perfect CCs. Pressure was the only parameter that registered a discernable bias, which was slightly negative for this dataset (meaning that the *convertdata* values tended to be slightly lower than those from the MMS). This difference is likely due to the different ways in which pressure is interpolated in the two software sets. The MMS Met message software uses a linear interpolation scheme, whereas *convertdata* uses a more meteorologically accurate logarithmic approach. The MB of -0.15 mbar was considered to be insignificant.

While these data were extremely encouraging, the T&E IPT determined that other types of Met messages should be compared before final approval of *convertdata* would be granted. Three days from the 11-case dataset from Ft. Sill, OK, for which there were complete Target Acquisition Messages (METTA1) and Fallout Messages (METFM1, a.k.a., the "Basic Wind Report"), were selected. Minor modifications to *cmm_compare.m* were made to accommodate the different formats and Met parameters of the MMS METTA1 and METFM1 messages. The METTA1 used the ambient temperature (as opposed to the virtual temperature) and also included the relative humidity (RH). Table 4 lists the results of this follow-on comparison study.

Table 4. Target acquisition and fallout Met message comparison statistics.

MMS METTA1 VS. 10-S METTA1				
	27-Jun-2001	**3-Jul-2001**	**15-Aug-2001**	**Average**
DIR MB	-0.70	1.10	-0.70	**-0.10**
DIR MAE	2.90	3.90	7.10	**4.63**
DIR RMSE	5.30	6.80	15.10	**9.07**
DIR CC	1.00	1.00	1.00	**1.00**
SPD MB	0.00	0.00	0.00	**0.00**
SPD MAE	0.20	0.10	0.10	**0.13**
SPD RMSE	0.40	0.50	0.30	**0.40**
SPD CC	1.00	1.00	1.00	**1.00**
TMP MB	0.00	0.00	-0.10	**-0.03**
TMP MAE	0.10	0.10	0.10	**0.10**
TMP RMSE	0.20	0.10	0.10	**0.13**
TMP CC	1.00	1.00	1.00	**1.00**
RH MB	-0.20	0.30	-0.30	**-0.07**
RH MAE	0.80	1.20	0.50	**0.83**
RH RMSE	1.20	1.90	1.00	**1.37**
RH CC	0.99	0.99	1.00	**0.99**
MMS METFM1 VS. 10-SEC METFM1				
	27-Jun-2001	**3-Jul-2001**	**15-Aug-2001**	**Average**
DIR MB	-3.30	3.30	0.00	**0.00**
DIR MAE	5.60	3.30	0.00	**2.97**
DIR RMSE	8.80	5.80	0.00	**4.87**
DIR CC	1.00	1.00	1.00	**1.00**
SPD MB	0.40	0.10	0.10	**0.20**
SPD MAE	0.40	0.30	0.30	**0.33**
SPD RMSE	0.50	0.40	0.40	**0.43**
SPD CC	1.00	1.00	1.00	**1.00**

NOTE: DIR indicates wind direction (measured in mils), SPD indicates wind speed (measured in knots), TMP indicates temperature (measured in K).

As with the 11-case comparisons, very little difference was found between the Met messages generated directly by the MMS and those produced by *convertdata*. For each of these analyses, the minor differences that did occur could probably be attributed to the time resolution of the raw input data. The raw data observed by the MMS were in approximately 1-second intervals, whereas the *convertdata* was in 10-second increments. It was assumed that by inputting 2-second data into *convertdata* during the DT, even less difference would result. Based upon these findings, the T&E IPT approved the use of *convertdata* on the DT datasets.

4. A Met Accuracy Program

In order for the MMS-P to pass one of the major decision points in its development (the Milestone-C Decision, which determined whether the system would proceed into DT), we had to make a preliminary assessment of the Met accuracy of its MM5 model and post-processor. Two Met accuracy datasets were collected via rawinsonde observations—one for Ft. Sill, OK (summer 2001), and the other for the East Coast (EC) (winter/spring 2002 and spring/summer 2003). These datasets were in a so-called 53-level format[6] (see table 5) in order to include all possible zone heights from various types of artillery Met messages. Typically, such datasets have been referred to as ground-truth data.

Table 5. An excerpt from a 53-level, ground-truth data file.

```
outfile          /tmp/met_out_BWI.20020410110000.txt
date             20020410
time               110000
latitude         39.18000
longitude       -76.67000
altitude         47.0
ceiling       30000.0
visibility    11936.9
snowrate          0.0
rainrate          0.0
number_levels    53
level 01 agl      0 ws   3.2 wd 321.4 tc   11.2 rh  83.8 pa 1018.5
level 02 agl     50 ws   4.9 wd 325.2 tc   11.0 rh  82.0 pa 1012.6
level 03 agl    100 ws   6.5 wd 327.0 tc   10.8 rh  80.1 pa 1006.5
level 04 agl    200 ws   8.0 wd 329.7 tc   10.2 rh  78.2 pa  994.5
level 05 agl    300 ws   9.0 wd 331.9 tc    9.7 rh  77.1 pa  982.6
level 06 agl    400 ws  10.0 wd 334.0 tc    9.1 rh  76.4 pa  970.8
level 07 agl    500 ws  11.0 wd 335.6 tc    8.5 rh  76.0 pa  959.1
level 08 agl    600 ws  11.1 wd 336.2 tc    8.0 rh  75.6 pa  947.5
level 09 agl    700 ws  10.9 wd 336.3 tc    7.5 rh  74.6 pa  936.0
level 10 agl    800 ws  10.6 wd 335.9 tc    7.2 rh  71.8 pa  924.7
level 11 agl    900 ws  10.1 wd 334.9 tc    6.9 rh  67.3 pa  913.5
level 12 agl   1000 ws   9.4 wd 332.5 tc    6.7 rh  63.1 pa  902.4
```

[6] Although these files actually do contain 53 levels, for the sake of brevity, only those up to 1000 m AGL are shown here.

In order to evaluate the system's Met accuracy, a set of criteria was required that could compare the forecast data from the MMS-P against the OK and EC datasets.

Development of a suitable set of Met accuracy criteria was no simple task for several reasons: 1) we had to consider the specific elements within, and the underlying intent of, various requirements documents, such as the MMS-P Operational Requirement Document; 2) we had to address concerns of the Prime Contractor and several organizations within the user, test, and meteorological communities; and 3) we had to deal with the fact that the MMS-P's MM5/post-processor software system operates at a much smaller temporal and spatial scale than any other Met model previously adopted for operational use. Furthermore, the level of scrutiny being applied to the evaluation of this modeling system was far greater than had ever been applied before (with the exception, perhaps, of meso/microscale models operating in pristine research environments). Thus, the Met accuracy criteria had to be tailor-made to address these issues.

ARL expended significant effort in developing the required set of Met accuracy criteria. Several iterations of modifications were made under the direction of the T&E IPT. Table 6 is a primarily narrative synopsis of the final set of criteria, hereafter called the Profiler Test Criteria (PTC). As indicated in table 6, the PTC are applied on a line-by-line basis, comparing MMS-P forecasts to the OK and EC ground-truth datasets. Some of the criteria are applied equally, regardless of which line (height) in the file is being compared. For example, at 80 percent of all the lines (i.e., all the samples), the MMS-P forecast pressure must fall within 3 mbar of the ground-truth value, with an overall MAE of 4 mbar. For other criteria, the threshold values (maximum allowable differences) must be computed for each line. For example, the maximum allowable wind vector error is either a function of the height within the Boundary Layer (BL) or of wind speed at levels above the top of the BL.

Table 6: Proposed PTC, excerpted from the MMS-P test documentation, 21 May 2002.

Local – Position MMS, Radar, Radiometer etc. 30 km from Profiler. MMS-P Met CM sfc – 30km AGL validated by radar and radiometer compared to MMS Met CM, line by line	**Target – Position MMS, Radar, Radiometer etc. 60 km from Profiler.** MMS-P Met CM sfc – 5km AGL validated by radar and radiometer compared to MMS Met CM, line by line
Temperature (virtual) - 80% of all samples ± allowable error of $\Delta T_{ve} = \Delta T_e + 0.061 w_s T$, where ΔT_e is the base allowable temperature error (no humidity) = 2.0 C, w_s is the saturation mixing ratio at the current air temperature, T. w_s may be computed or extracted from a table. The numerical value is a constant (0.61) used in the definition of virtual temperature times 0.1 to account for the allowed 10% error in relative humidity. MAE of all samples ≤ 3.0C	Temperature (virtual) - 75% of all samples within ± the allowable error (ΔT_{ve}) as defined for the "Local' case. MAE of all samples ≤ 3.0C
Pressure - 80% of all samples ± 3mb. MAE of all samples ± 4mb.	Pressure - 75% of all samples ± 3mb. MAE of all samples ± 4mb.
Wind Vector error computed from speed and direction reported in Met CM. MAE of all samples ≤ 3 ms^{-1}. 80% of all samples within ± V_{error}, where $V_{error} = [2V^2(1-\cos\theta) + 2V\Delta V(1-\cos\theta) + \Delta V^2]^{1/2}$, and where ΔV = 2.6 ms^{-1} (5 kts), V is actual wind speed, and θ = allowable direction error. θ will vary from 45° at the surface to 11.25° (200 mils) at h, where h is the top of the boundary layer as determined from the data, nominally 2000m as a fall back, but can vary and be much lower at night. The formula for the value is $\theta_{max} = \theta_{top} + [(\theta_{sfc} - \theta_{top})(1-(z/h)^n)]$, where n = 1.5. Allow additional ± 2.5° if use WMO format messages as "ground truth." For wind speeds ≥ 30 ms^{-1} at altitudes > h, there will be: - a linear decrease in allowable direction error (θ_{max}) as wind speed increases from V = 30 ms^{-1} to 60 ms^{-1}; from 11.25° for 30 ms^{-1} to 6° at 60 ms^{-1}, constant thereafter at 6° (plus additional ± 2.5° if WMO). - a linear increase in the maximum allowable speed error from 2.6 ms^{-1} to 3.6 ms^{-1} as wind speed increase from V = 30 ms^{-1} to 60 ms^{-1}, constant thereafter at 3.6 ms^{-1}.	Wind Vector error computed from speed and direction reported in Met CM. MAE of all samples ≤ 3 ms^{-1}. 75% of all samples within ± the allowable error (V_{error}) as defined for the 'Local' case. MET TALL Parameters – All measured at 60km from Profiler. Consensus of meteorologists required on sample prior to evaluation.
	Precipitation Type and Rate – as judged by Meteorologist aided by rain or snow gauge. Profiler required to predict correct type 75% of the time correctly. Profiler able to predict snow ± 2 in/hr, rain ±0.5 in/hr 75% of the time
	Cloud Ceiling – 75% off all samples ± 500m to 1st broken or overcast layer. Meteorologist consensus on sample, required.
	Visibility – Visible Spectrum, Predict either greater than 2 km or less than 2 km., 75% of the time correctly as judged by meteorologist.

NOTE: MET-TALL = Met message-Target Area Low Level

During the summer of 2002, we developed a MATLAB program called *metacc3* that incorporated the PTC for wind vector, virtual temperature, and pressure error; calculated (in the case of wind vector and virtual temperature error) and applied the maximum allowable values at each line; and indicated the Pass/Fail ratios for all 53-levels in the data files. The *metacc3* code only deals with the basic Met parameters of virtual temperature, wind vector, and pressure. The other parameters listed in Table 6 (precipitation type/rate, cloud ceiling height, and visibility), which require interpretation by a meteorologist, are not included in the *metacc3* analysis.

A number of hand-calculations were made using the PTC, against which the output of *metacc3* was compared. Also, Penn State University, the original developer of MM5, conducted some quick-look calculations using the PTC. In all cases, the results of *metacc3* were verified as accurate. After the T&E IPT was briefed on the functional aspects of *metacc3*, the Prime Contractor, Smiths Aerospace (SA), requested a copy of the source code. Under an ARL Software Release Agreement with SA, the *metacc3* code was delivered to their software developers during the summer of 2002. The MATLAB programming language is very similar to the C language, consequently *metacc3* was converted to C code by SA and adopted for use in all subsequent Met accuracy analyses. Figures 4a-4c contain a block diagram of the *metacc3* MATLAB code.

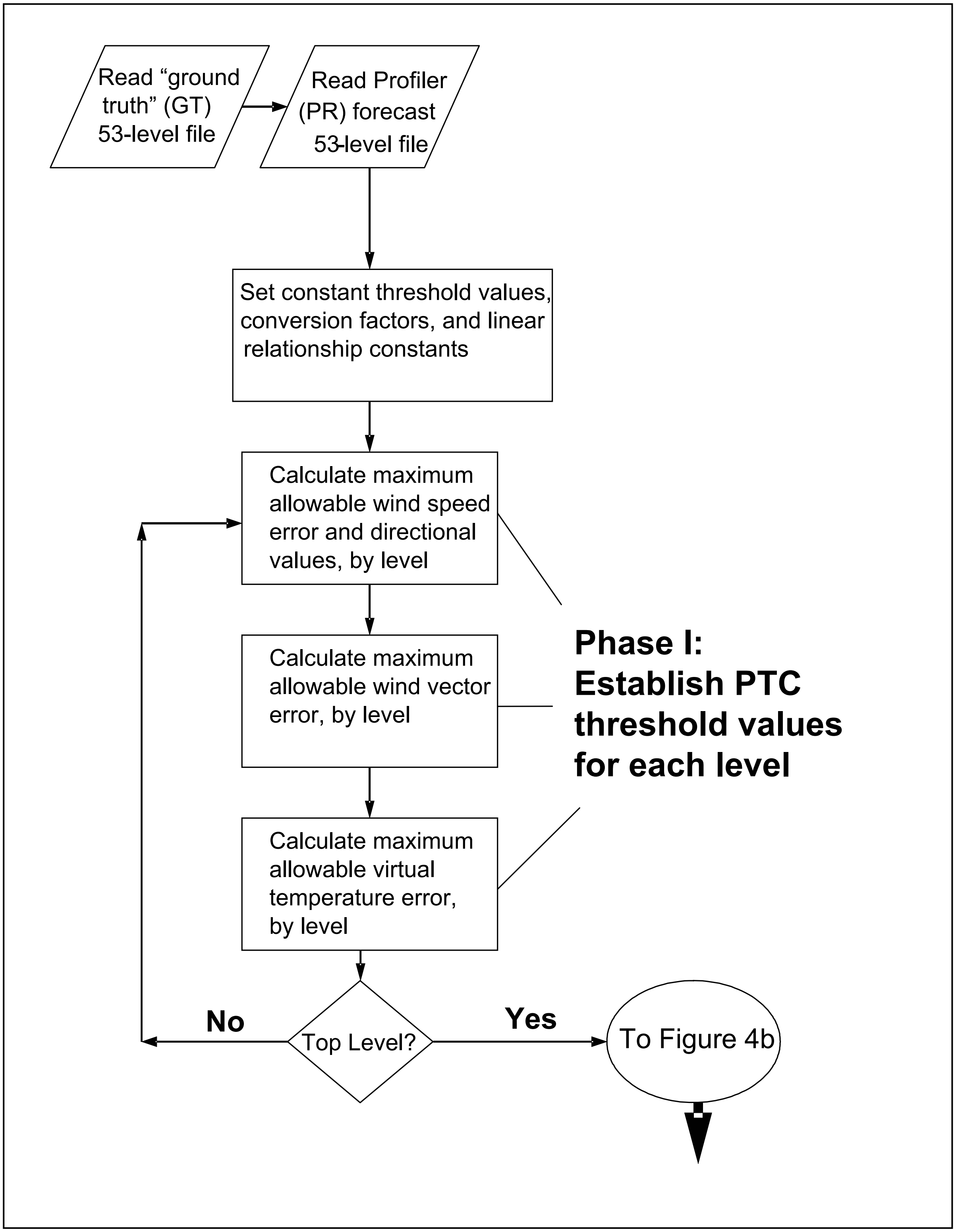

Figure 4a. *metacc3* block diagram.

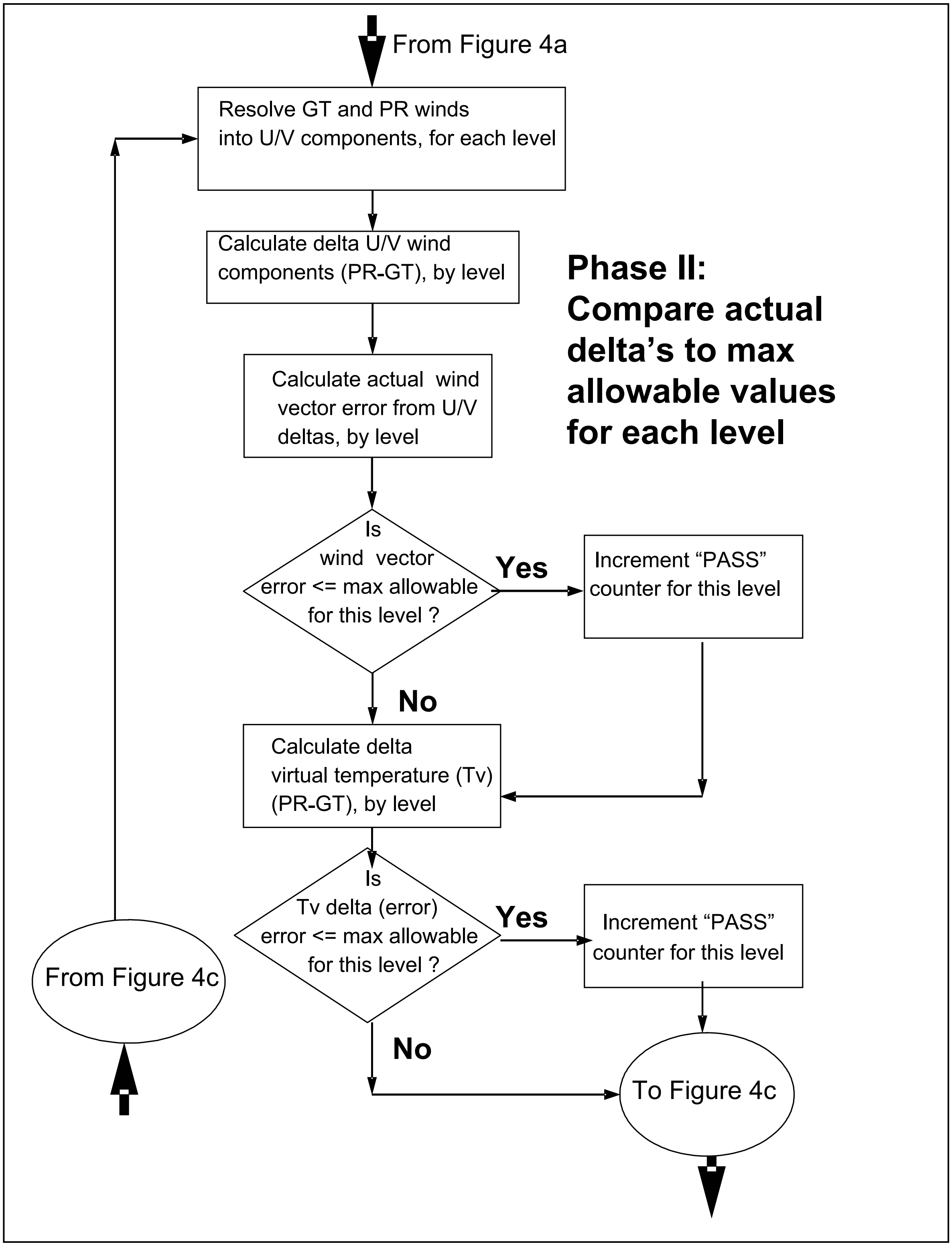

Figure 4b. *metacc3* block diagram (continued).

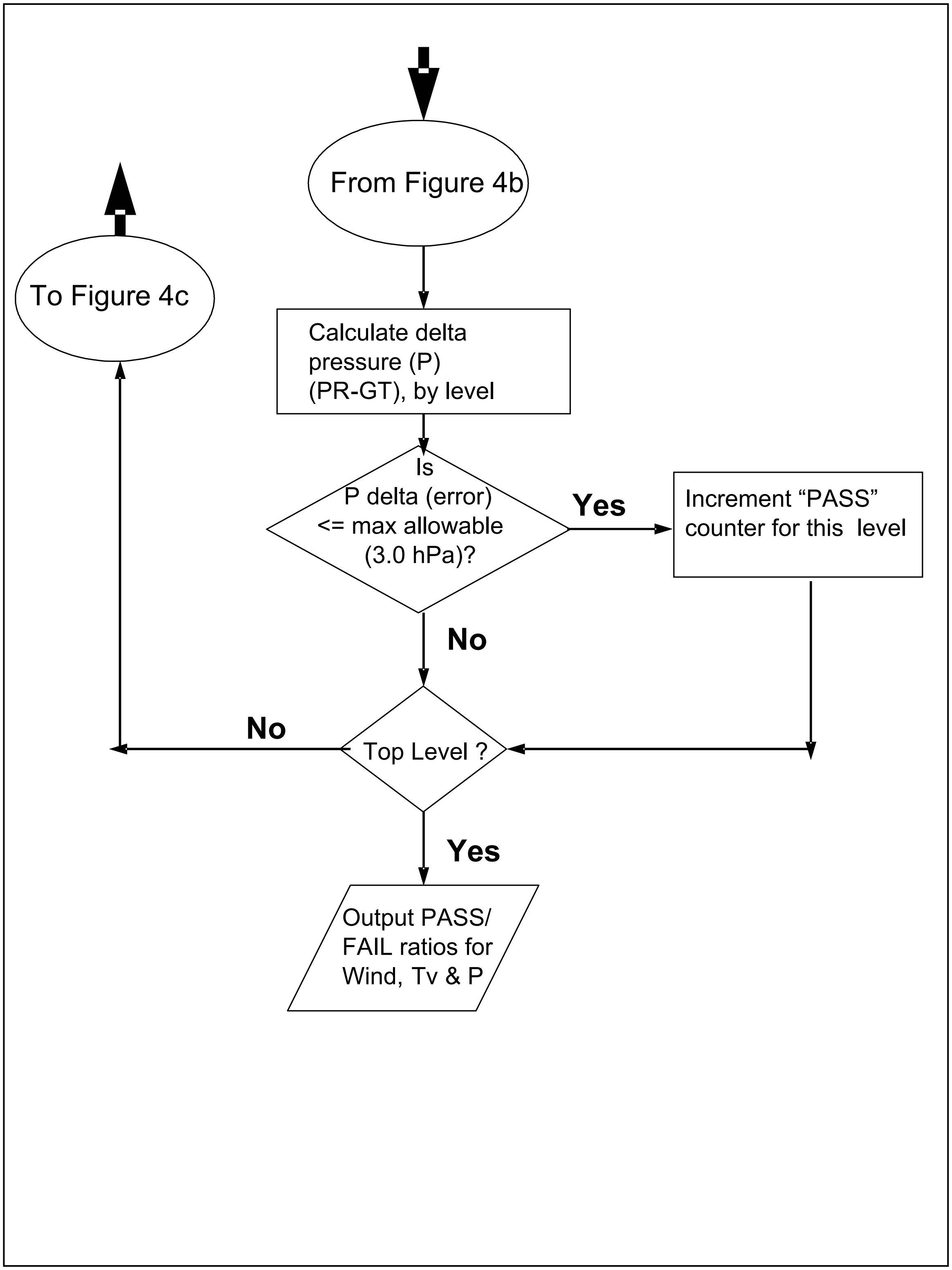

Figure 4c. *metacc3* block diagram (continued).

In preparation for the DT, a methodology was required for evaluating the accuracy of the artillery Met messages that would be produced by the Profiler. Although the same PTC were to be applied to the evaluations, Met messages would be compared, rather than the files in the 53-level format. SA developed an Excel workbook to accomplish this analysis task. However, the T&E IPT preferred that the government conduct independent analyses of the DT datasets in order to spot-check the accuracy of the results produced by SA. Consequently, the *metacc3* code was modified to accommodate this analysis (this modification was called *compare_metcm*), and it retained essentially the same block diagram as for *metacc3*. Several datasets were analyzed during the course of the DT, using both the Excel workbook and *compare_metcm*, and the same PASS/FAIL ratios were obtained.

5. Conclusion

At the request of the PM-TIMS, ARL/CISD/BED provided software to generate MET messages in several formats and to provide statistical analysis of these messages and tests results of the MMS-P. The PM and the T&E IPT also requested that BED transfer versions of both software products to the MMS-P prime contractor, SA. The algorithms expressed by the MET message codes became part of the MMS-P system software. Both the MET message generation program (a.k.a., *convertdata*) and the statistical analysis programs were used by government and contractor personnel to evaluate the performance of the MMS-P during the DT and other tests of the system. Due to the flexibility built into the MET message software, the software can be used for additional vertical structures of Met data with very minimal modification (e.g., it would require just setting up a new **_lvls* file and changing input and output file names). Also both the message generation and statistical analysis software packages may be used for experiments that require any vertical structure of layered data, including new messages types that may be devised for non-line of sight systems of the future. The statistical analysis programs can be applied to other sets of Met data with minimal modification. These software packages have helped BED contribute to the development and testing of an Army system that represents the first major upgrade on artillery meteorology systems in over two decades.

6. References

Cogan, J. *A Technique for Computation of Meteorological Variable Profiles for User Defined Heights and Layers*; ASL-TMR-0005; U.S. Army Atmospheric Sciences Laboratory: White Sands Missile Range, NM, 1990.

Cogan, J.; Izaguirre, A. *A preliminary Method for Atmospheric Soundings in Real Time Using Satellite and Ground-Based Remotely Sensed Data*; ARL-TR-240; U.S. Army Research Laboratory: White Sands Missile Range, NM, 1993.

Department of the Army, Field Manual 6-15: Tactics, Techniques, and Procedures for Field Artillery Meteorology, Headquarters Department of the Army: Washington, DC, 1997.

Jameson, T.; D'Arcy, M.S. *Artillery Firing Simulations Using "Met-Along-The-Trajectory"*; ARL-TR-3221; U.S. Army Research Laboratory: White Sands Missile Range, NM, 2004.

Jameson, T. *Computer Met Message Accuracy Studies Relating to the Met Measuring Set – Profiler*; ARL-Project Report; U.S. Army Research Laboratory: White Sands Missile Range, NM, 2003.

Jameson, T.; Luces, S.; Knapp, D. *Effects on SADARM Trajectory Simulations Using Meteorological Input from Local Balloons and the Battlescale Forecast Model for the 2000 RDAP and LUT Firings*; ARL-TR-2720; U.S. Army Research Laboratory: White Sands Missile Range, NM, 2002.

North Atlantic Treaty Organization (NATO), NATO Standardization Agreement (STANAG) 4082: Adoption of a Standard Artillery Computer Meteorological Message, Brussels, Belgium, 1984.

Stauffer, D.; Seaman, N.; Schroeder A.; Deng, A.; Gibbs, A.; Hunter, G. Evaluations of a Rapidly Relocatable High-Resolution Numerical Model and Data Assimilation System for Meteorological Nowcasting. Twelfth PSU/NCAR Mesoscale Model Users' Workshop, June 24-25, 2002; Boulder, CO; 48-51.

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Appendix

1. Sample message output

The current versions of the message generation software produce five types of message output; the output data and formats are the same for all versions. Sample messages follow for all types for one sounding. The rawinsonde did not reach 26000 m AGL, so the maximum layer (zone) height was 24000 m. Note that the standard Teletype-style format is not generated in these cases, but the data values are the same. For example, temperature is given in K × 10; a value of 291.3 K is output as 2913 (K × 10).

a. The following message has data required for the METCM. Note that sensible temperature was added at the request of the T&E IPT for the MMS-P.

```
MET-CM output

Date: 28MAR04   Time: 16:02  Latitude:  32.37000     Longitude: -106.47000
Elevation: 1283.00     Ceiling:  -999.0     Visibility:  -999.0

 Line    Height  Wind Direction  Wind Speed   Virt Temp  Pressure  Temperature
           (m)   (tens of mils)     (kt)       (K*10)      (mb)       (K*10)

  0          0         18           12         2890       877        2887
  1        200        631           10         2860       867        2856
  2        500        592            9         2840       841        2836
  3       1000        573            9         2809       801        2805
  4       1500        559           14         2780       754        2778
  5       2000        511           13         2771       709        2769
  6       2500        515           14         2750       666        2749
  7       3000        535           16         2722       626        2722
  8       3500        510           19         2687       588        2687
  9       4000        494           23         2655       551        2655
 10       4500        480           25         2621       517        2621
 11       5000        470           28         2582       484        2582
 12       6000        489           27         2523       438        2523
 13       7000        479           28         2443       381        2443
 14       8000        495           30         2361       331        2361
 15       9000        483           33         2280       286        2280
 16      10000        474           35         2210       245        2210
 17      11000        476           41         2134       210        2134
 18      12000        491           49         2075       178        2075
 19      13000        517           35         2099       151        2099
 20      14000        523           21         2139       129        2139
 21      15000        441           19         2097       110        2097
 22      16000        474           24         2072        93        2072
 23      17000        506           19         2102        79        2102
 24      18000        578            5         2110        67        2110
 25      19000         54            6         2099        57        2099
 26      20000        130            5         2109        48        2109
 27      22000        167           12         2136        38        2136
 28      24000        270            6         2175        28        2175
```

b. The following message has data for the tam. A value of -999 means missing data or data excluded by the “gross error check” algorithm.

```
TAM output

Date: 28MAR04
Time: 16:02
Latitude:  32.37000
Longitude: -106.47000
Elevation: 1283.00
Ceiling:  -999.0
Visibility:  -999.0
Snow Rate:     0.0
Rain Rate:    0.00

Line Height  Virt Temp Pressure Wind Speed Wind Direction Temperature Rel Hum
       (m)     (K*10)      (mb)      (kts)  (10's of mils)   (K)        (pcnt)

  0       0     2890       877      11.7         18           2887        16
  1      50     2873       874      10.7          7           2869        20
  2     100     2860       869      10.1        635           2856        22
  3     200     2854       862       9.5        620           2850        23
  4     300     2847       851       9.0        603           2843        23
  5     400     2841       841       8.6        590           2837        24
  6     500     2832       831       8.4        581           2829        25
  7     600     2824       821       8.4        573           2820        26
  8     700     2817       811       8.4        570           2813        27
  9     800     2810       801       8.8        570           2806        28
 10     900     2801       792       9.4        574           2797        29
 11    1000     2791       782      10.0        579           2788        29
 12    1100     2784       772      10.7        582           2781        28
 13    1200     2778       763      13.2        579           2775        26
 14    1300     2773       754      14.5        570           2770        26
 15    1400     2773       745      15.9        549           2771        24
 16    1500     2793       735      16.3        527           2791        12
 17    1600     2788       727      14.7        518           2786        14
 18    1800     2774       713      12.5        507           2772        19
 19    2000     2759       696      13.8        510           2757        24
 20    2500     2750       666      14.0        515           2749         8
 21    3000     2722       626      15.6        535           2722         5
 22    3500     2687       588      19.1        510           2687         6
 23    4000     2655       551      23.0        494           2655         8
 24    4500     2621       517      25.5        480           2621        16
 25    5000     2582       484      27.9        470           2582        21
```

c. The following message has data for the bwind. A value of -999 means missing data or data excluded by the "gross error check" algorithm.

```
bwind output

Date: 28MAR04
Time: 16:02
Latitude:  32.37000
Longitude: -106.47000
Elevation: 1283.00
Ceiling:  -999.0
Visibility:  -999.0
Snow Rate:     0.0
Rain Rate:    0.00

 Line   Height   Wind Speed  Wind Direction
          (m)      (kts)      (tens of mils)

  0         0      11.7        18
  1      2000      10.7       558
  2      4000      17.7       511
  3      6000      26.6       482
  4      8000      29.2       487
  5     10000      34.1       478
  6     12000      44.9       484
  7     14000      27.6       519
  8     16000      21.3       459
  9     18000      11.5       521
 10     20000       5.0        89
 11     22000      12.1       167
 12     24000       6.0       270
```

d. The following message has data for the tacq. A value of -999 means missing data or data excluded by the “gross error check” algorithm.

```
tacq output

Date: 28MAR04
Time: 16:02
Latitude:  32.37000
Longitude: -106.47000
Elevation: 1283.00
Ceiling:  -999.0
Visibility:  -999.0
Snow Rate:     0.0
Rain Rate:    0.00
```

Line	Height (m)	Temperature (K*10)	Humidity (pcnt)	VirtTemp (K*10)	Pressure (mb)	Wind Speed (kts)	Wind Direction (tens of mils)
0	0	2887	16	2890	877	12	18
1	50	2869	20	2873	874	11	7
2	100	2856	22	2860	869	10	635
3	200	2850	23	2854	862	10	620
4	300	2843	23	2847	851	9	603
5	400	2837	24	2841	841	9	590
6	500	2829	25	2832	831	8	581
7	600	2820	26	2824	821	8	573
8	700	2813	27	2817	811	8	570
9	800	2806	28	2810	801	9	570
10	900	2797	29	2801	792	9	574
11	1000	2788	29	2791	782	10	579
12	1100	2781	28	2784	772	11	582
13	1200	2775	26	2778	763	13	579
14	1300	2770	26	2773	754	15	570
15	1400	2771	24	2773	745	16	549
16	1500	2791	12	2793	735	16	527
17	1600	2786	14	2788	727	15	518
18	1700	2776	18	2779	718	13	511
19	1800	2767	19	2769	709	12	503
20	1900	2758	25	2761	700	14	503
21	2000	2756	22	2758	692	14	518
22	2100	2759	15	2760	683	14	522
23	2200	2755	9	2756	675	13	518
24	2300	2748	7	2749	666	13	512
25	2400	2745	5	2745	658	15	510
26	2500	2740	5	2741	650	16	514
27	2600	2735	5	2736	642	16	527

e. The following message has data for the balis. The values are different in that temperature is the percentage relative to a "standard" temperature; the same is true for the density. Standard formulas, as found in the relevant manuals, are used to compute density and convert the units to percent of standard. For example, a value listed under temperature that is greater than 100 means that the temperature for that line exceeds that found in the standard profile. A value of -999 means missing data or data excluded by the "gross error check" algorithm.

```
balis output

Date: 28MAR04
Time: 16:02
Latitude:  32.37000
Longitude: -106.47000
Elevation: 1283.00
Ceiling:  -999.0
Visibility:  -999.0
Snow Rate:     0.0
Rain Rate:    0.00

 Height   Line  Wind Direction  Wind Speed  Temperature  Density
   (m)          (10s of mils)     (kts)      (pcnt std)  (pcnt std)

      0     0         18          11.7         100          86
    200     1        631           9.9          99          87
    500     2        592           8.6          99          87
   1000     3        573           9.0          99          87
   1500     4        559          13.8          99          87
   2000     5        511          13.4         100          86
   3000     6        526          14.7         101          86
   4000     7        501          21.0         101          86
   5000     8        475          26.7         100          86
   6000     9        489          26.7         100          87
   8000    10        487          29.2          99          87
  10000    11        478          34.1          98          88
  12000    12        484          44.9          96          88
  14000    13        519          27.6          98          86
  16000    14        459          21.3          96          87
  18000    15        521          11.5          97          85
```

2. Code samples

Samples of two key routines are presented here in the form of "pseudo code." Terms enclosed between a "/*" and "*/" are comments.

a. The level function is used in the generation of artillery Met soundings or any other user defined atmospheric structure of heights and layers. It produces values at the user defined height levels.

```
Include the standard C libraries (e.g., stdio.h, stdlib.h, math.h, etc.).
In the function level pass the following variables: the maximum height
(zmax), the maximum size of the output arrays/user input levels (htsize), the
array of user defined levels (zh), the array of sounding values (value), the
array of output values (lev_value) for the defined levels zh, and the array
of sounding heights (z).
 {

 Set indices to initial values, i=0, j=0.

  While (z_j < zmax and zh_i < zmax and i < htsize)
    {
      if(zh_i ≥ z_sfc)
        {
          if(zh_i = z_j)
            {
              lev_value_i = value_j;
              add 1 to j;
            }
          else
            {
              if(z_j > zh_i)
                subtract 1 from j;

              lev_value_i = value_j - (value_j-value_j+1)*(zh_i-z_j)/(z_j+1-z_j);
            }
         }

      While (zh_i+1 ≥ z_j+1 and z_j+1 > .00001)
         add 1 to j;

       add 1 to i;
    }
    return to calling program;
}
```

b. The layer function is used in the generation of artillery Met soundings or any other user defined atmospheric structure of heights and layers. It produces values for layers (weighted or integrated mean) defined by the user defined levels.

Include the standard C libraries (e.g., stdio.h, stdlib.h, math.h, etc.).

In the function layer pass the following variables: the maximum height (zmax), the maximum size of input/temporary arrays (size), the maximum size of the output arrays/user input levels (htsize), the array of user defined levels (zh), the array of sounding values (value), the array of level values (lev_value) for the defined levels zh as computed from the level function, the output array of layer/zone values (lay_value), and the array of sounding heights (z).

```
 {

 Set indices to initial values, i=0, j=0.
 Define local arrays of dimension "size": tempval,  tempz, mean.
 Define the variable sum.

  While(i < htsize-1 and zh_{i+1} ≤ zmax)   /* Find layer averages.*/
    {
      add 1 to i;
      set ind = 0 and sum = 0;
      tempval_{ind} = lev_value_{i-1};          /* Lower boundary value*/
      tempz_{ind} = zh_{i-1};
      For (j starting at 0 increasing to a value not to exceed 'size'
incremented by 1)
        {
          if (z_{j} < zh_{i} and z_{j} > zh_{i-1})        /* Values within layer.*/
            {
              add 1 to ind;
              tempval_{ind} = value_{j} ;
              tempz_{ind} = z_{j};
            }
        }
      add 1 to ind;                               /* Upper boundary level.*/
      tempval_{ind} = lev_value_{i};
      tempz_{ind} = zh_{i};

      For (j starting at 0 increasing to a value of 'ind' incremented by 1)

/* Sub-layer average.*/
        {
          mean_{j-1} = (tempval_{j} + tempval _{j-1}) * 0.5;
        }

      For (j starting at 1 increasing to a value of 'ind' incremented by 1)
                                   /* Proportional weighting of each layer.*/
        {
           add  mean_{j-1} * (tempz_{j} - tempz_{j-1}) to sum;
        }

      lay_value_{i-1} = sum /(zh_{i} - zh_{i-1}); /* Mean layer value.*/

    }    /* end of while loop.*/

  return to calling program;
}
```

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Acronyms

AGL	above ground level
ANSI	American National Standards Institute
ARL	U.S. Army Research Laboratory
balis	Ballistic Met
BED	Battlefield Environment Division
BL	Boundary Layer
bwind	Basic Wind Message
CC	Correlation Coefficient
CISD	Computational and Information Sciences Directorate
DT	Developmental Test
EC	East Coast
FA	Field Artillery
GPS	Global Positioning System
GT	ground truth
IPT	Integration Process Team
LORAN	long range navigation
MB	Mean Bias
MAE	Mean Absolute Error
MATLAB	Matrix Laboratory
Met	meteorological
METCM	computer Met message
METFM1	Fallout Messages
METTA1	Target Acquisition Messages
MET-TALL	Met message-Target Area Low Level
MM5	Mesoscale Model Version 5
MMS	Meteorological Measuring Set
MMS-P	Meteorological Measuring Set – Profiler
MSL	mean sea level
NATO	North Atlantic Treaty Organization

P	pressure
PM-TIMS	Product Manager – Target Identification and Meteorological Systems
PR	Profiler
PTC	Profiler Test Criteria
PTU	pressure/temperature/humidity
raob	rawinsonde observation
RDF	Radio Direction Finder
RH	relative humidity
RMSE	Root Mean Square Error
SA	Smiths Aerospace
SDD	System Development and Demonstration
STANAG	Standardization Agreement
tacq	Target Acquisition
tam or TAM	target area meteorological message
T&E	Test and Evaluation
UTC	universal time coordinated
WSMR	White Sands Missile Range

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